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Refurbishment of a multistorey residential building in st. Petersburg to reduce energy consumption

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DESCRIPTION

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Abstract

Every year the price of heating in Russian Federation is getting higher and higher. Because of this residents think energy efficiency in their houses to save money. In the nearest future some measures must be done about energy efficiency. One of these measures is refurbishment. During the refurbishment with improving building envelope, windows and joints; we can achieve well-done construction with lower losses and reduce energy consumption. It is the most common way to reduce energy consumption in residential buildings built between 1960 and 1990 years.

The aims of this work are: to know, what the energy consumption building has now and how it will change after refurbishment; to calculate the investment part of changes in envelope which include cost of materials and installation works; to find out how long payback period of renovation will be.

In order to reach specified aims the following methods are applied. The first method is literature research. Method of analysis and description of the building envelope will be applied. Secondly heat losses will be calculated for existing building. And for three more models after refurbishment: with new parameters of glazing, with adding insulation and with full refurbishment with insulation and glazing. Only insulation and glazing will be chosen because they are easy to change and convenient to reinstall. Next goes analysing of energy consumption before and after the renovation, which will be calculated with IDA ICE simulation software. In the end formulas of investment efficiency will be applied to find out the payback period.

This thesis describes several of refurbishment models which lead to energy saving. In this work different models are compared to find out the most significant and efficient variant both for energy saving and for residents’ budget.

Subject headings, (keywords)

Refurbishment, envelope, energy consumption, building simulation, investment cost, operational cost, payback period.

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1 INTRODUCTION

1.1 General overview

About twenty-thirty years ago Russian engineers didn’t have so many possibilities to use various types of insulation and construction materials. Sometimes they built in a hurry or didn’t receive enough state subsidies. It causes of great energy consumption which implies big spending for heating.

Every year the price of heating is getting higher and higher. That is why people start thinking about energy efficiency to save their money. In the nearest future something must be done about energy efficiency. Also because of a law about energy efficiency in Russian Federation. Energy efficiency can be achieved only by reducing heat losses. In this way buildings need considerable improvement to meet satisfactory quality norms. If we improve building envelope, windows and joints, we can achieve well-done construction with lower losses and reduce energy consumption.

Every year 10 000 000 m^2 of buildings are refurbished in Russia. Most of these residential buildings built between 1960 and 1990years.Now it is necessary to reduce energy consumption, this can be achieved by improving their indoor quality and thermal efficiency./1./

Today people are spending their money trying to save indoor heat. The most common and easy way to do this is changing windows. It is possible to increase energy efficiency in high-rise buildings, carried out as part of their refurbishment, and look at the benefits that investment in energy efficiency can provide.

It is interesting to see the changes in indoor climate parameters depending on types of construction elements and then analyze them in conformity with requirements of energy efficiency. Furthermore investment part is rather important, because everyone calculates their money and it is important that such kind of refurbishment will have beneficial effect.

1.2 Aims

There are several aims in this work. The first of them is to know, what the energy consumption building has now and how it will change after refurbishment. Naturally it shows differences between materials and their thermal parameters. In my case there are old construction materials with their properties and new ones. New materials, for example insulation has enough high thermal resistance, which is better than already existing materials.

The second aim is to calculate the investment of changes in envelope. This calculation will include cost of materials and installation works. All prices will be updated to today date for the consumer. Middle prices of materials will be taken for this research. Chosen materials are enough good quality and reasonable price.

The final aim is to find out how long payback period of renovation will be. Energy consumption of building will be taken into account during calculations. Finally time period had to be found. This period shows phase after which invested money will return to customer and users start to benefit from the investment in this refurbishment.

1.3 Methods

In order to achieve the goal, the following methods are applied. The first method is literature research. There are not many information about such kind of refurbishment. Method of analysis and description of the building envelope will be applied.

Secondly in this research work heat losses will be calculatedfor existing building. It will be the first model. The second model will be calculated with new parameters of glazing, third model will describe building with adding insulation and the last one will describe building after full refurbishment with insulation and glazing. Only insulation and glazing will be chosen because they are easy to change and convenient to reinstall.

Next step in my work is analyzing energy consumption before and after the renovation. The energy consumption of building will be simulated with IDA ICE software.

New type of windows and insulation will be used in simulation. That should have great effect on thermal conditions in whole building.

Also one major point of this research is to find out efficiency of these refurbishments. For this purposes formulas of investment efficiency will be applied to find out the payback period.

A multistorey building located in Saint-Petersburg will be taken for this research. This type of building was built in 1980s to provide housing for a large number of people. That is why frequently engineers didn’t care about good insulation. It is interesting to know quality of this buildings according to standards and look how given changes will influence the conditions in the apartments.

The selected type of building are located in Saint-Petersburg. It has nine stories and three typical sections. Building envelope is made of concrete blocks. Windows are made of wood frames with three glasses. Natural ventilation is used in this building.

2 ENERGY EFFICIENCY IN RUSSIA

Russian economy is one of the most power-consuming economics in the world. Russia takes the third place in the world for power use. In this list Russia goes after China and United States of America. Inefficient usage leads to losses of energy up to 40% from all produced power in the country. If it will be compared with equivalent fuel this amount could be the same volume as 400 million tons and power production of 100 large combined heat power plant. About 45% of all produced power goes for residential buildings' heating needs, which consists from more than 2.8 milliard square meters./2./

Federal law (FL) about № 261-FL "About energy conservation and increasing the energy efficiency in buildings, and about corrective actions in separate legislative acts of Russian Federation". In this document certain arrangements are offered. One of the general directions is changes in energy consumptions of residential buildings.

Major requirements about new buildings and already existing buildings are introduced in this low:

- Accordance with exacting requirements about energy efficiency and prohibition of commissioning without claims settlement;
- Installation of energy supply measuring devices in all types of residential buildings;
- Responsibility of builders in accordance to energy efficiency requirements of energy efficiency during at least 5 years;
- Introduction of energy classes and notification residents about this class, for instance on multistorey house façade. Example of such table is given on figure 1.

FIGURE 1.Table with energy class of building mounded on the façade/2./

Principal potential of energy conservation based on refurbishment of existing buildings were built till 1994. These buildings were built before implement the requirements about energy efficiency. That is why renovation of existing buildings is one of the common directions in energy conservation to achieving them to conformity with norms of thermal protection and energy consumption.

3 MULTISTOREY RESIDENTIAL BUILDINGS IN RUSSIA

3.1 General information about series housing construction

Powerful sector for the production of precast concrete has been established by the end of the 1950s in Russia. It corresponded to the rapid expansion of the mass of Housing Construction. Mass production of advanced industrial decorating materials has been established at the same time. These include: tile, drywall, tape, slab, wallpaper.

Since the early 1960s, housing construction in the Union of Soviet Socialist Republics was based on commercial buildings. It were constructions of 5 and 9-story series of panel houses.Entering of such buildings decreased construction costs and made it possible to increase living space. This made it much more comfortable than communal apartments. Therefore every apartment was designed on the basis of population of one family, instead of several. Serial houses from the "blocks" began to appear. Along with the construction of large buildings. They were constructed from a panel of the same, but not the whole wall./3./

Several house-building factories were organized from 1959 to 1962 in Leningrad. Here are some of them: Polyustrovsky DSC-1, Obukhov DSC-2, DSC-3 Avtovskaya, Kuznetsovsky DSC-4, Kolpinsky DSC-5, Nevsky DSC-6, Gatchina DSC. Complex method of construction of multistorey buildings was first introduced at these companies with the inclusion of the manufacture, delivery and installation of the panels in a single cycle./4./

In the 1960s, mass housing construction gained momentum by applying industrial prefabricated elements in new areas of the city: Grazhdanka, Polyustrovo, Dachnoyeand Big Okhta. Constructions were conducted on Moscovsky and Novoizmaylovskya venues. Constructions of memorials were ended at Piskarevskoe and Seraphim' cemeteries. The hard work continues reconstruction and restoring monuments of architecture and culture of St. Petersburg./4./

At the same time, the development of a new master plan for Leningrad has been started. The General Plan has already been approved by the Council of Ministers of The Union of Soviet Socialist Republic in 1966. Architects of the General plan were

V. Kamensky, A.Naumov, G. Buldakov.It was envisaged in the General Plan to form a "sea front" length of about 30 km from Olgina to Strelna districts , to drain wetlands of the delta of the Neva River, to expand the territory of the city through the reclamation soil./4./

Expansion of the Seaport, reconstruction of the airport "Pulkovo" and railways were provided. The requirements were put forward for the establishment of regional cultural centers, development of individual architectural solutions, unconventional design compositions. The total area of the housing stock of the city was assumed to increase in 20-25 years to 53 million m ^{2}./4./

However, from 1966 to 1983, was built 40 million m^2 of living space. Free planning of districts has been widely applied in the field of urban development, which excludes close courtyards so typical for old St. Petersburg./4./

For this a common type of building in St. Petersburg have been chosen . The 606-series of houses is a project of 606 series industrial housing construction. Construction of prefabricated houses of 606 series is a project "LenNIIProekt" since the 1970s to the present time in St. Petersburg and some of its suburbs. In other cities do not meet. Apartments of 606 series are considered housing economy class./1./

It is the one of the common series of the sample mass housing of the second half of the 1960s, its producers Polyustrovsky and Kuznetsovsky house-building. These buildings were built from 1967 to 1973 and featured improved consumer characteristics compared to 602-th series. Because of that the houses of 606-th series were widespread. Shops often located on the first floor, thereby making them uninhabitable./5./

In this type of prefabricated buildings, we can talk about the diversity of facades for the first time: the central part of the section protrudes forward from the entrance to the apartment, forming a ledge with a staircase-lift unit and two one-room apartments. This apartment has kitchen –8square meters, room – 15.7 square meters, hallway with built-in wardrobe and separate bathroom.

3.2 Housing quality for residents

Apartments of 606 series are the most comfortable and warmest houses from all prefabricated buildings of that time period. General facts of existing type of building are given in table 1.

TABLE 1. General facts of chosen type of buildings

Series:	1-LG606
Floors:	9story
Material of the external walls:	concrete panels
The height of dwellings:	250 cm
Apartments:	one, two, three-room
Years of construction:	1967-1973

Hollow core slabs and floorings provide good sound insulation. The thick external walls with broad window sills provide less dependence of home comforts from changes in wind direction. Well-thought-out design of apartments reliably insulated from neighbors on the floor: a good sound insulation is present in these buildings; all walls between apartments are bearing in the standard production version. Moreover, quality hardwood floors were common in the rooms of such buildings, as well as a good waterproofing in the bathrooms.

There are also serious drawbacks. For example, the ceiling joists are located in "steps" along the walls in kitchens and bathrooms. They reduce the height of the room at the wall to 2.35 meters. In addition suspended ceiling represents the "pie" of the concrete slab with thickness of only 5 cm, which laid joists and planks, and considerable layer of sand. When repairing a flat with replacement floors it is necessary to be extremely careful. When drilling holes for fixing new joists you can easily punch a hole to the neighbors’ flat./5./

4 ENVELOPE

The building envelope separates the outdoor environment from interior of the building. It includes foundation, exterior walls, roof, doors and also windows. Envelope is such kind of thermal barrier, it play key role in regulation indoor air quality: temperature, humidity, air change rate. If we know construction of envelope, we can determine energy requirement to maintain thermal comfort and future energy consumption as well. Minimizing heat transfer through the building envelope helps to reduce heat losses and needed heating and cooling demand, also electrical systems. Interaction of HVAC with components of envelope, and activities of residents, might affect the performance of the building envelope./6./

4.1 Walls

Walls are the basic structural unit in a building. Facades of buildings should meet accepted standards of thermal performance of spaces, provide sound insulation, fire resistance and to be strong and durable. The amount of lost energy through walls is influenced by materials and design. Design of construction such as orientation, number of stories, placement of windows and doors, their size and location can affect to the energy consumption. Decisions regarding the selection of the material may be especially important because energy properties of the whole building depend on them. It is important that selection of materials and wall insulation can both affect the building's thermal properties. A building envelope has ability to store heat. This ability is determined by the building materials which are used. Envelope absorb heat energy during long time period and then hold it for a long time also. It effectively reduces temperature difference between indoor and outdoor air, reducing total heating and cooling demands.

In our case we have a prefabricated building. The structural layout is designed as frameless with longitudinal bearing walls. Lateral stiffness of the building is provided by frequent walls with ventilation valves and continuous concrete walls between the sections.

The interior walls are made of reinforced concrete grade 200, or cinderblocks thickness of 200 mm. The walls between rooms are made from a single drywall, between the apartments are made of double drywall. And intersectional walls are made of concrete thickness of 130 mm. External walls are made of cinderblocks with thickness about 400 mm and density γ=1500kg/m3. Decorating the exterior walls made with ceramic tiles. Principal construction of walls can be seen on Figure 2./7, 41-42./

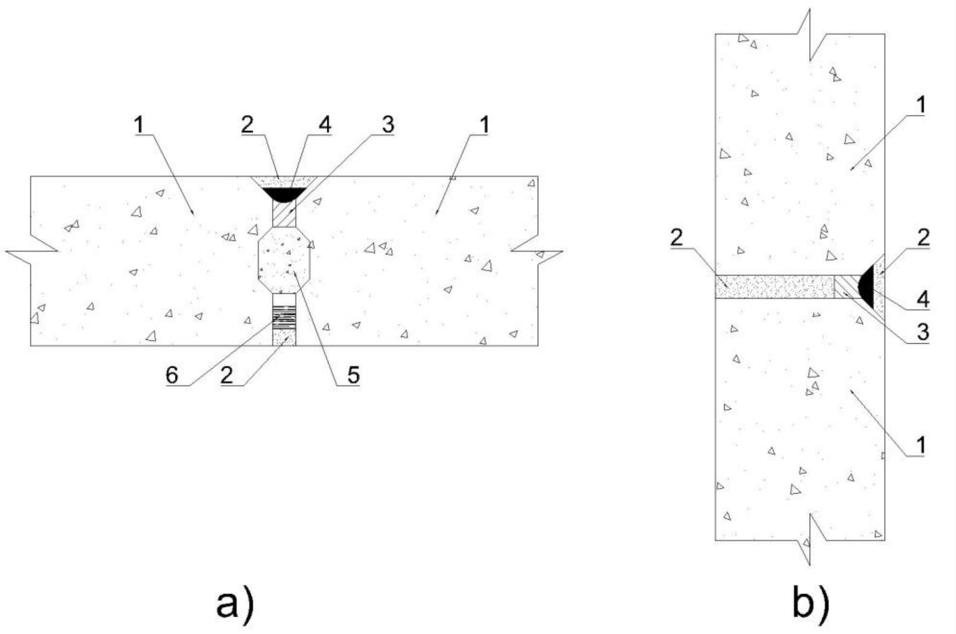

FIGURE2.Joints between the external wall panels

a) Vertical joints

b) Horizontal joints

1 - outdoor cinderblock wall panel; 2- grout; 3 - porous rubber gasket; 4 – mastic;
5 - slag concrete; 6 - sealing tarred oakum.

Cinderblock is quite durable and lightweight material. Cinderblock is cheaper in about half, and provides heat protection half times greater than brick. The walls are quite durable, which are built of this material. Walls will serve at least 50 years, if they are made with reliable foundation, a well-executed protection from moisture and the proper masonry.

Thermal protection properties and quality, strength cinderblock are also depending on the ratio of fine and coarse particles of slag aggregate. This ratio is called the particle size of slag concrete. To achieve more common characteristics of external walls it is necessary to have certain ratio of fine and coarse particles of slag. This ratio should be 7/3 or 6/4.

Strength is the central value for the construction of interior walls (load bearing walls) of the house. Therefore, the percentage of fine slag should be large, and extra-large lump slag should not be part of the cinderblock at all. Sand is added in an amount of about 20% of the total mass of the material instead of the fine slag to make material stronger.

4.2 Insulation

Nowadays construction industry is developing in high speed. Building materials start to be more quality and have wide variety of selection. Customers can choose any of them. Everything depends only on needs and solvency. It is also good on the early stages of construction, but it can’t be solve of given problems for already build buildings.

Heat properties of insulating materials and construction materials are known or can be exactly measured. The amount of heat flow can be calculated by means of any combinations of materials. It is also necessary to know and understand some technical parameters to calculate the heat losses and take into account factors that effect on it.

The major value for insulation materials is coefficient of heat transmission which named in literature as U-value. This coefficient shows thermal resistance of any materials. U-value is the ratio of the temperature difference on the surfaces of the building envelope. It shows the amount of the heat flow per unit area through it. The lower U-value, the better is the insulating material. To compare insulation with different thicknesses and thermal conductivity, heat transfer coefficient should be calculated for each./8./

Heat flow is always directed from a warmer to a cooler space. In cold weather, the heat from the house goes to the cold outside air. The colder outside the faster warm air move through building envelope from the house. Therefore, the thermal insulation of walls is one of the main sources of energy saving.

It is possible to achieve significant reduction of heat losses if customer will warm up its house with quality modern insulation materials. The effect of this event is economic and ecological. It depends on different factors such as climate, location, shape of building envelope and also from existing fee for energy. Therefore, manufacturer recommend to contact the designers to help more precisely calculate effect of thermal insulation of walls and if it is necessary investments.

Wall insulation with use of modern insulation improved thermal resistance properties to reduce the overall thermal resistance of the wall or it causes the decreasing the heat transfer coefficient.

Also, insulation prevents "thermal bridges" that occur when one of the materials is a heat conductor and it creates thermal bridges between warm indoor microclimate of the house and outside cold air. Such "thermal bridges" are often a source of significant heat losses from the building envelope.

External method of thermal insulation is the most common method in Russia. Temperature distribution in the wall is shown on figure 3. On this figure it is possible to see how temperature changes through material layers.

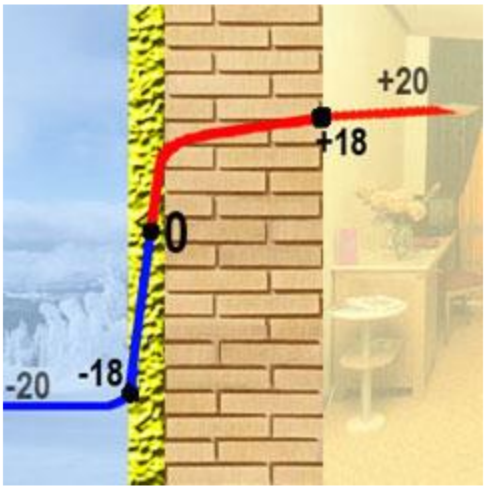

FIGURE 3. Method of external thermal insulation

Method of external thermal insulation gives possibilities to improve thermal performance of envelope, to extend the period of its operation, to prevent mechanical deformations due to low external temperatures differences in walls, to increase the hydrophobic characteristics of the envelope, to reduce breathability and sound transmission, to provide a high level of energy efficiency and reduce fee of the heating energy up to 60%. During using this method it is necessary to carry out the thermal insulation around the windows to prevent condensation.

One of wide spread type of external insulation is ventilated facade insulation system with an air cavity. It is a structure in which insulating boards of rock wool are fixed on the surface of the facade with dowels. Decorative tiles are used to protect insulation from the weather. They are mounted on a metal structure. Facing is installed at a distance from the insulation layer and it provides a ventilated layer to remove moisture from the construction./9./

Special feature of mounted façade system with ventilated air gap is presence of air movement inside gap. Because of it the highest requirements of fire protection produce to insulation layer. Construction of ventilated façade is shown on figure 4 which is developed by ROCKWOOL Company.

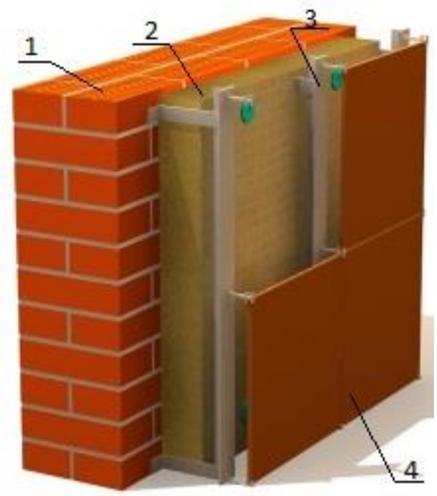

FIGURE 4. Ventilated façade/9./

Construction of ventilated facade:
1 –external wall; 2 – insulating material; 3 – dowel; 4 – decorative tiles (panels, siding, ceramic).

In systems ventilated facade insulation layer may be formed in two ways with a single layer or two layers. To simulate the energy consumption in refurbishment of the building will be used single layer solutions using ROCKWOOL VENTI BATTS insulating panels.

Thickness of this panels is determine in accordance with the norms for thermal protection called SP 50-13330-2012 «Thermal protection of buildings» and in accordance with thermal homogeneity coefficient of mounted wall system. Pressed facade panels are made of rock wool could be used as facing. It is necessary to provide air gap of 60 mm width and free movement of air in it on all surfaces of facade./9./

As it is said earlier in simulation will be applied ROCKWOOL insulation type VENTI BATTS. It is strong thermal insulation slab with hydrophobic properties made on synthetic sticker. VENTI BATTS are made of rock wool based on basalt rock group. Some properties of this mineral wool is written in following table 2. /10./

TABLE 2. Technical characteristics of ROCKWOOL VENTI BATTS /10./

Parameter	Value	Units
Dencity	90	$kg/_{m^3}$
Thermal conductivity	0,035	W/(m·K)
Compressive resistance	20	kPa
Breaking point	4	kPa
Water adsorbing during	1,5	% in volume
Vapor permeability	0,30	mg/(m·h·Pa)

Mechanical installation of ROCKWOOL VENTI BATTS makes with special plate-shaped dowel. Dowels should be deepen in foundation minimum in 30 mm. Amount of dowels is calculated by designer of façade system. /10./

4.3 Basement

Basements are made of concrete floors. This type of overlap as is the most reliable in the monolithic and prefabricated design. The basic defects that requires is removal of excessive deflections; freezing; peeling plaster layer, cracks in the ground support on the wall, between the panels of the ceilings high soundproofing of airborne and impact noise. On figure 5 shows the common types of concrete floor.

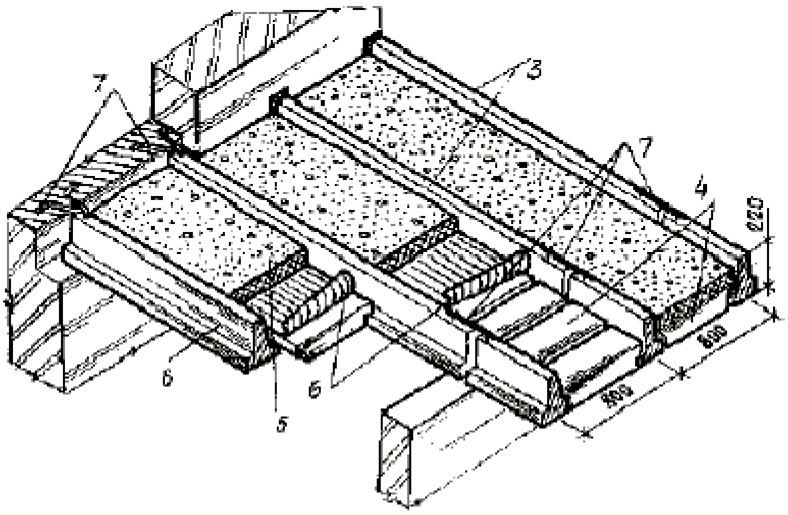

FIGURE 5.Concrete floors/11./

1 - concrete hollow-core slabs; 2 - loops for lifting; 3 - concrete beams; 4 – beams; 5 –thermal insulation and sound insulation;6 –vapor insulation;7 – anchors.

Presence of plaster on the lower surfaces of concrete slabs especially on ceiling is very dangerous. Plaster may be collapse, if it is getting wet, so plaster must be removed and replaced with other structural elements during repairs.

The moisture combined with chemicals such as sanitary units, leaks in the communications lead to the corrosion of concrete rebar and then, despite the durability of concrete floors, walls, has the same durability as the foundations in capital building.

Moreover in exploitation should be excluded such effects in a timely manner, eliminating the cause. So it should also provide insulation in freezing locations layers by restoring insulation in cold basement ceilings, corners and areas bearing on the wall.

For exclusion displacement of insulation layer, for example slag, expanded clay, attics should be arranged with sand-lime layer. Floor slabs over the built boiler room, laundry, shops and other facilities with discharge hazards must have a reliable insulation and be gastight to protect dwellings from odors.

4.4 Roof

Roof of multistorey residential building in most cases create with concrete slab as basis, vapor insulation, waterproof layer, thermal insulation, but it could be without it also. Heat aspires to upward. Due to this condition bad insulated roof could be source of considerable heat losses. Using of insulation can reduce up to 20% of outgoing heat through building envelope.

Using of thermal insulation rock wool could achieve reasonable increasing of acoustical comfort for residents of last floor. It also could reduce noise caused by rain and storm.

4.5 Windows

Not less significant part of envelope are windows and doors. The placement of windows and skylights and other sources of available natural light affect the amount of materials and installation. Also it can affect the amount of transmitted energy through the windows and doors as well as the amount of air leakage through these components. Developing of new materials, types of construction and designs have contributed to the improved energy efficiency of high-performing windows, shells and buildings. /12./

Heat loss through the window occur due to

- loss through the window unit
- losses through the covers (thermal bridges, leakages)
- losses due to thermal conduction of air
- convective flows between glasses
- thermal radiation

Single-or triple-pane windows are used in modern translucent constructions of thermal protection of windows. To carry out casements and boxes used wood, aluminum, fiberglass, plastic profiles, or combinations of them. Windows using the float-glass provide the design thermal resistance less than 0.56 $m^2 \cdot {}^\circ\mathrm{C}/_W$/11./

Heat absorbing glazing is used to improve the energy efficiency of glass constructions. It contains a certain percentage of metal, which absorbs radiation with wavelengths greater than 0.7 nm. Heat capacity of glazing depends on the angle of the sun and glass thickness. Heat absorbing glass is always located the outside. Heat reflective glasses are covered with polymer or metal films. Heat transfer coefficient of such windows is 0.2-0.6$^{W}/_{m^2 \cdot {}^\circ C}$. In several countries three-layer heat reflecting films are used to reduce heat transfer coefficient to 0.13 $^{W}/_{m^2 \cdot {}^\circ C}$./12./

There are at least four categories of windows frames - wooden, plastic, aluminum, wood and aluminum. All these windows are being divided on the materials from which they are made. But we will cover the most commonly used. It has plastic windows and wood.

4.2.1 Wooden windows

Wooden windows with two bindings were used in buildings in 1960-1990s. This means that a window frame mounted two frames. In this case the flaps are: open up into the room, open in all directions (one inside, one outside), move to the side and move up. In 606-series buildings used wooden double glazed windows are opened into the room. Wooden double glazed windows which are into the room are the most convenient in terms of operation. They are easy to open and close, remove and hang the flaps, change and wash glass. It is easy to mention on the picture on figure 6. When fully open the window sashes are not exposed to rain and wind.

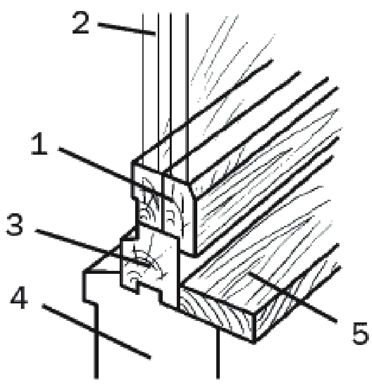

FIGURE 6.Installation of wooden windows with double glazed windows and paired bindings/13./

Explication of numbering in the figure:

1 –binding; 2 – glass; 3 – box; 4 – wall; 5 – windowsill.

The main disadvantage of this design is the structural complexity of binding. In order to sash parallel opened into the room, external and internal bindings should have different sizes. In particular the inner must be greater than the external. The difference in size between the external and internal binding is called clearance. Due to this difference in size consumers have an exploding problem with the leak proofness of windows after a certain period of time./13./

4.2.2 PVC windows

PVC windows represents a metal frame which is externally covered PVC (polyvinyl chloride). These windows are convenient in installation, have a low weight, easy to clean are resistant to dust and moisture protection have, high thermal insulation and noise insulation, large area of glazing (or in the house will be much more light). This type of windows also has some advantages and disadvantages. There are list of benefits.

The durability. According to the advertisement, the service life PVC windows up to 50 years. It should be added that the period of real life of plastic windows - is three times smaller. Nothing will happen if the window you will stand for 50 years. But you will need to change the accessories, tighten up all sorts of adjusting screws, etc. Care for the PVC windows is minimal. Of course, time and quality of service depends on moldings of the window from which the window was made./14./

Meteo sustainability. PVC windows are resistant to all weather influences./14./

Tightness. Noise insulation and heat insulation. PVC windows is rescue from noise, dust, cold and drafts. Especially noticeable advantage of soundproofing when the windows of apartment are looking toward roadway. The obvious plus is insulation. There is no need to insulate the windows in the winter. The emergence of drafts during installation this type of window is minimized. Plastic moldings and window provides insulation soundly in the room./14./

Environmental friendliness. Production of PVC windows is environmentally friendly. PVC windows does not pollute environment during manufacture process. Plastic is totally recycled and does not give harm effect on the nature and to human health. Additional advantages of PVC windows that these windows do not decompose as wood and do not afraid of microorganisms They are even protected from the ultraviolet rays. They do not warp or swell./14./

Fire resistance. Modern plastic windows do not support combustion. In the preparation of the recipe of PVC windows includes substances such as fire retardants. Moreover, if the apartment will fire, windows with a good glazing can prevent the spread of fire. Usually, even if the windows are bursting with fire in the apartment, the flow of air fanning the flames. PVC has good thermal insulation. Therefore, if the first glass will burst because of strong temperature changes, the second window will stand for a while and will not let the fire extend, due to slower heat up./14./

Acceptable price. Perhaps it is the most powerful argument. The cost of wooden windows is about the same as the cost of modern PVC window. But the indicators for noise insulation and tightness significantly lower./14./

What about disadvantages? PVC has static electrical charge. This means that they will attract dust like a magnet. It would be desirable the fact that they are not suitable for repair, the plastic cannot just be repaired. Scratch or crack will remain on the case of windows. PVC windows have lower heat transfer values comparing with wooden ones. Expansion coefficient of the profile is large enough. This suggests that in extreme cold profile will be much compressed, on the other hand in hot weather it will expand. To eliminate this disadvantage it is necessary to think about complicated system profiles.

> "*REHAU window and door systems, manufactured using approved profiles extruded within ISO 9001 Quality Management System in accordance with the requirements of BS EN 12608 (BSI Kitemark License KM 13358) and registered with BBA (Report No's 1930, 1108 and 1309), have been type tested and certified to performance standards:- BS 7412 - Specification for window and door sets made from PVC-U.*"
> */15./*

For simulation REHAU windows will be chosen. Model of this named REHAU Sib-Design. System of this type of windows was developed special for Russian customers. The basis of the concept is the criterion used in any climate zone. As is well known heat losses go throughout the surface of the window. The company has developed a special REHAU profile with a section width of 70 mm with the possibility of double-glazed window with thickness up to 44 mm to minimize heat losses. Reinforcement is also used in the profile what allows to produce window units with larger doors. Especially actual for the residential buildings of the Soviet period.

PVC windows REHAU Sib-Design have high consumer properties and will reliably protect home from bad weather and aggressive environment of the city by supporting the room comfortable microclimate.

PVC windows REHAU Sib-Design are made of RAU-PVC. RAU-PVC was specially designed for plastic windows and for exploitation in any climate. High reliability of plastic windows made of RAU-PVC, does not require special care, well served ordinary cleaning cloth and water. PVC profile of REHAU RAU-PVC steady to UV, does not absorb dirt and dust of the city. REHAU Sib has high sound insulation performance due to the wide profile of 70 mm and two circuits sealing windows. Other properties of this type of windows is written in following table 3 /16./

TABLE 3. Technical indicators of profile REHAU Sib-Design /16./

Parameter	Value	Units
Thickness	70	mm (with seals)
The number of cameras	3+1	(with thermo block)
Maximum glazing thickness	44	mm
Thermal resistance	0.72	$\frac{m^2 \cdot °C}{W}$
Sound protection	Up to 4th class (VDI 2719)	
Air resistant and water resistant	up to load group "C"	
Box width of reinforcement	42	mm
Instalation depth	115	mm
Overlap of seals	3	mm

REHAU windows are recommended for the renovation and construction of new buildings with high requirements for thermal insulation and design. This type is most popular in private houses and apartments. REHAU windows are wide spread among users because of its construction and dimensions, which are shown on figure 7.

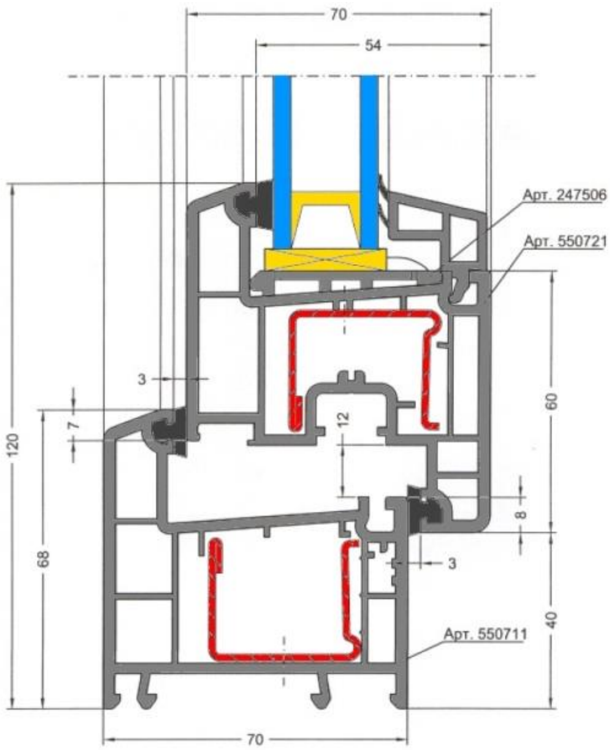

FIGURE 7.Technical dimensions of the profile REHAU Sib-Design /16./

System of additional air chamber "Thermostabil" is used in the system REHAU Sib-Design. It creates a favorable microclimate in the premises. "Thermo-block" is a modern solution designed to improve the thermal insulation properties of PVC windows REHAU. It uses air as an effective insulation material. Thereby significantly reduce the cost of production. Thermoblock is Additional insulating air chamber between the reinforcement and the inner wall of the profile provides effective thermal insulation with depth of 70 mm. This thermoblock decision can be seen on figure 8. Thermal resistance (R = 0,71$\frac{m^2 \cdot ℃}{W}$)./16./

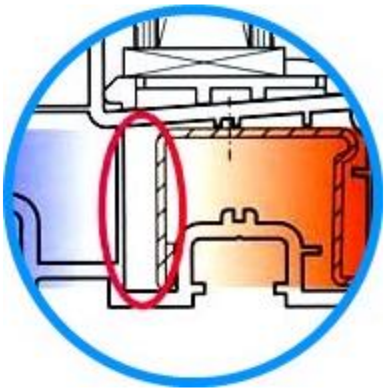

FIGURE 8.Thermal insulation REHAU Sib-Design /16./

5 HVAC SYSTEMS

5.1 Water supply and heating

Mostly open system of water supply and heating are presented in Russian multistorey residential buildings. Open district heating systems means that water is the same in both systems the DHW system and the radiator network. Partly water goes to water outlets. The rest of hot water in the system is used for heating and ventilation. Water flow rate in the heating system is balanced by additional amount of water is supplied to the district heating network. The main advantage of open heating system is economic benefits. In the Soviet Union period, close to 50% of all heating systems are open.

Open system could be connected with heating network in the dependent scheme via elevators and pumps. And with an independent scheme using heat exchangers. Independent open system is more expensive, but it gives greatly improved water quality compared to the dependent.

Moreover it is necessary to keep slope of the horizontal tubes within the limits 0.005-0.01% in direction from the building systems as radiators and water outlets, and then to the heating networks.

But also this system has several disadvantages. First of all, water in such system has rather poor quality of hygiene. Heat emitters, pipe networks impact color, odor, various impurities and bacteria can appear in water. To prevent these problems high qualified purification methods is used in wastewater treatment plants. It reduces economic benefits of this method and makes price for water higher.

Hot domestic water must comply with GOST 2874-82 "Drinking Water. Hygienic requirements and quality control". SNIP 2.04.01-85 * is regulating the temperature in the water outlets not lower than 60 °C for centralized hot water systems that are attached to open heating systems, as well as systems for local needs.

Heating system should be designed according to SNIP 2.04.05 "Heating ventilation and air conditioning" on compulsory application. For heating systems should be used as a heat transfer agent water on most cases, other fluids may also be used at the feasibility study. According with chapter 3 “Heating systems”, paragraph 3.20 the temperature limiting of the heat transfer agent should be equal to 95°C for residential, public and administrative buildings for heat emitters, heated with water.

For design one pipe heating system was selected, it described on figure 9. One sided radiator connections with bypass were applied. Nowadays on most of them thermostatic valves are installed.

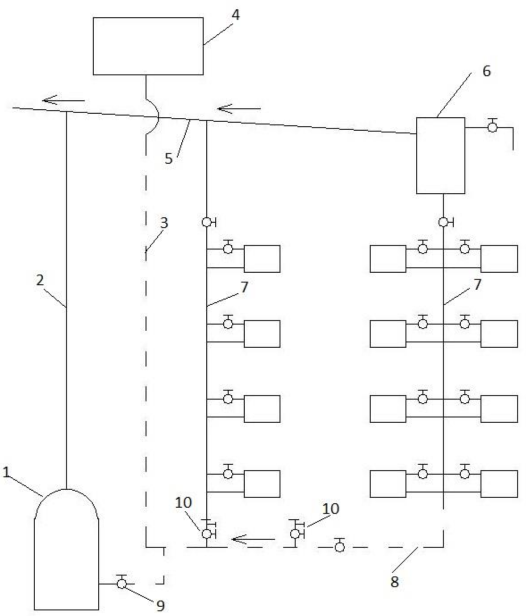

FIGURE 9.One-pipe systems of water heating

1 - a copper; 2 - the main strut; 3 - a broad pipe; 4 - a broad tank; 5 - a submitting line; 6 - an air collector; 7 - struts; 8 - a return line; 9 - the pump; 10 - tees with stoppers

But in some cases there are no pumps in such systems.

5.2 Ventilation

In residential buildings of 606-series resents only natural ventilation. SNIP 2.08.01-89 "Residential buildings" recommends the following scheme of ventilation of apartments: outside air enters through the open windows of living rooms and removed through the exhaust grilles installed in kitchens, bathrooms and toilets. Air change apartment must be at least one of the two times: the total volume of air extracts from toilets, bathrooms and kitchens, which, depending on the type of cooker and should be 110 - 140 m^3/h, or standards inflow equal to 3 m^3/h per $m^2$of living space. Natural ventilation is general variant ventilation for multistorey residential buildings in Russia.

At present the principal natural ventilation scheme is multistorey buildings, which includes vertical collecting channel - "trunk" - with side branches - "associates.", as shown on figure 10. Air enters through the side branch exhaust port, located in the kitchen, bathroom or toilet. Usually installed in the floors above the ceiling and air goes to the trunk bypassed collecting channel. This scheme has good aerodynamic stability and meets the requirements for fire safety.

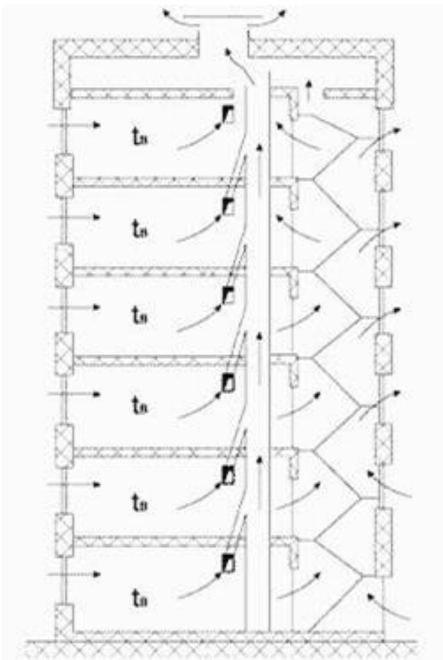

FIGURE 10. Forming of air flows in residential building/17./

Standard designs of multistorey buildings device provides a "warm loft" height of about 1,9 m in order to reduce heat losses through the ceiling of the top floor, and for increasing the temperature on the inner surface. Air from several prefabricated vertical channels comes into it, which makes total horizontal section of ventilation system.

If outdoor temperature starts to decrease air thrust will be increased. It is considered that ventilation of apartments only improves. At the same time the air flow rate exhaust system is only one component of flat air balance. Significant part of ventilation takes airflows, or exfiltration and infiltration through windows and behaving. This values could be different under various weather conditions and wind directions, open or closed window. One of the ways to deal with the overflowing of air through the staircase and elevator shaft is to design floor corridors or halls with a door separating the stairs and an elevator to the apartment unit. Such variant of floor design was applied in 606-series type building.

6 CALCULATION MODEL

One of the most common tendencies of the modern architecture and civil engineering is energy saving and improving energy efficiency. An important task in this regard is an adequate definition of thermal protection qualities of the building envelope. Solution of this problem allows assessing the compliance of structural construction with requirements, to establish the actual heat loss, to develop measures to improve the thermal protection of buildings./18./

In such a way calculation of heat losses is the most important part of design new building or in renovation as well. Heating needs of buildings are in depending on location, orientation, annual temperatures, wind power, humidity and amount of solar radiation.

6.1 Heat loss through building envelope

Heat losses through building envelope is important value for building and systems design. Calculations are based on Finnish regulations D5 “Calculations of energy consumption and thermal efficiency needs for buildings” and D3 “Energy Efficiency of

Buildings". And calculation of requirement thermal resistance is based on Russian regulations: GOST 30494, SNiP 23-01-99*, SNiP 23-02-2003.

Firstly it is necessary to find out suitable for indoor air conditions thermal resistance. Which will satisfy to requirement one and provide good conditions according with chosen construction design. Requirement thermal resistance R_{req}, $\frac{m^2 °C}{W}$ is determine due to D_d. Heating day degrees D_d, °C·days can be calculated with formula 1.

$$D_d = (t_{int} - t_{ht}) \cdot Z_{ht} \tag{1}$$

where

$t_{int} = 21°C$. Inside air temperature according with requirements of GOST 30494 table 1 as available inside air temperature;

$t_{ht} = -1{,}8°C$. Average mean temperature during heating period. Value is taken according with SNiP 23-01-99* table 1;

$Z_{ht} = 220°C$. Lasting of heating period per year in days. Value is taken according with SNiP 23-01-99* table 1;

$$D_d = (21 - (-1.8)) \cdot 220 = 5016\ °C \cdot \text{days}$$

Requirement thermal resistance of building walls calculated with formula 2. The same value will also apply for roof construction, if it is flat roof without loft. This construction are present in 606-series building, which is calculating.

$$R_{req} = D_d \cdot a + b\,\frac{m^2 °C}{W} \tag{2}$$

a=0.00035, b=1.4. Coefficients are determined depending on type of building. Value is taken according with SNiP 23-02-2003.

$$R_{req} = 5016 \cdot 0.0035 + 1.4 = 3.15\ \frac{m^2 °C}{W}$$

Requirement thermal resistance above basement $R_{req} = 4.15\,\frac{m^2 °C}{W}$.

Heating losses of infiltration have a significant place in calculations. Leakage air transfer outside air into a building through joints between parts of construction elements such as external walls and floors and also because of bad tightness of windows. About 30% of heat losses is due to leakage air. So reducing of infiltration could yield enough considerable energy saving. To define infiltration it is necessary to know value of flow rate of leakage air. Amount of leakage air define according with D3 and calculate by formula 3.

$$q_v = \frac{q_{50}}{3600 \cdot x} \cdot A_{ES} \tag{3}$$

q_v	Flow rate of leakage air m^3/s;
q_{50}	Air leakage number of the building structure, $m^3/h \cdot m^2$;
x.	Factor, depending of numbers of floors
A_{ES}	External surface area, m^2
3600	Convert factor s/h

In case of this design we have value of q_{50} equal to $4 m^3/h \cdot m^2$, x=15 for buildings with five or more floors according with regulation D3.

$$q_v = \frac{4}{15} \cdot 1 = 0{,}267\ {m^3}/{h}$$

After refurbishment amount of leakage air will be decrease because of changes in air tightness of window's frames, glazing and joints between walls.

$$q_v = \frac{3}{15} \cdot 1 = 0.200\ {m^3}/{h}$$

6.2 Input values

For simulation of building envelopes will be applied IDA ICE software. With the help of auxiliary units you can easily change the properties of the indoor climate, the number of occupants, degree of light, coolant parameters. Due to the theme of this thesis the most important are the changes in the construction and properties of the wall of windows that will be subject to refurbishment.

Typical Russian residential building is taken for simulation process in IDA ICE, it is shown on figure 11. Because of IDA ICE has not got in database Russian locations climate and other settings has been chosen for Helsinki (Ref 2012), Finland. Due to the fact that St. Petersburg and Helsinki has the similar climate, including annual temperatures, wind power, humidity amount of solar radiation.

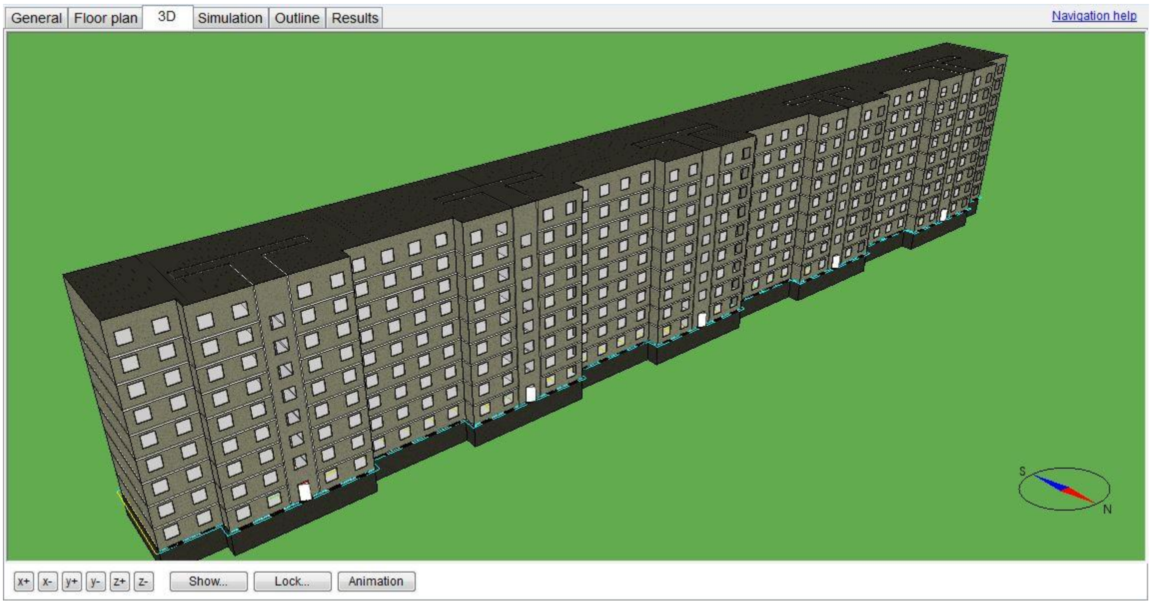

FIGURE 11. Building model

For next calculations it is significant to know building parameters: perimeter, square, volume, areas. This values can be founded from table 4.

TABLE 4.Building liner parameters

Parameter	Value	Units
Model floor area	16138.5	m^2
Model volume	46718.3	m^3
Model ground area	1777.4	m^2
Model envelope area	12193.9	m^2
Window/Envelope	13.3	%
Envelope area per Volume	0.261	m^2/m^3

To determine thermal loads of building it is necessary to know general internal heat gains. According with D3 National Building Code of Finland in our building will present the following values for residential building block, which are taken from chapter

“Standard use and indoor thermal loads of the building”, paragraph 3.3.5 and shown into the table 5.

TABLE 5.Indoor heat gains

Parameter	Standard value from D3	Annual energy use
Lightning	11W/m^2	57.82 kWh/(m^{2}a)
Device	4 W/m^2	21.02 kWh/(m^{2}a)
Occupants	3 W/m^2	15.77 kWh/(m^{2}a)

Based on calculations from D3 density of persons is one person per 28 m^2 and total square of living spaces is 14361.55 m^2. Thereby amount of presented people in building is 513 persons. But not all this amount of people will present in the building. It could be happened because of most of residents leaves theirs apartments in day time, while they are on the job, at school or in the university. Average presence of residents in household is about 60% from all time.

Energy consumption of domestic hot (DHW) water is 600 dm^3/(m^{2}a) for residential building block. Pipes of DHW and heating system has poor insulation, so it is also marked into settings of simulation program and later will be taken into account during analyzing process. All needed extra energy losses for simulation are submitted into figure 12, taken from IDA ICE. Coefficients of performance are shown on figure 13.

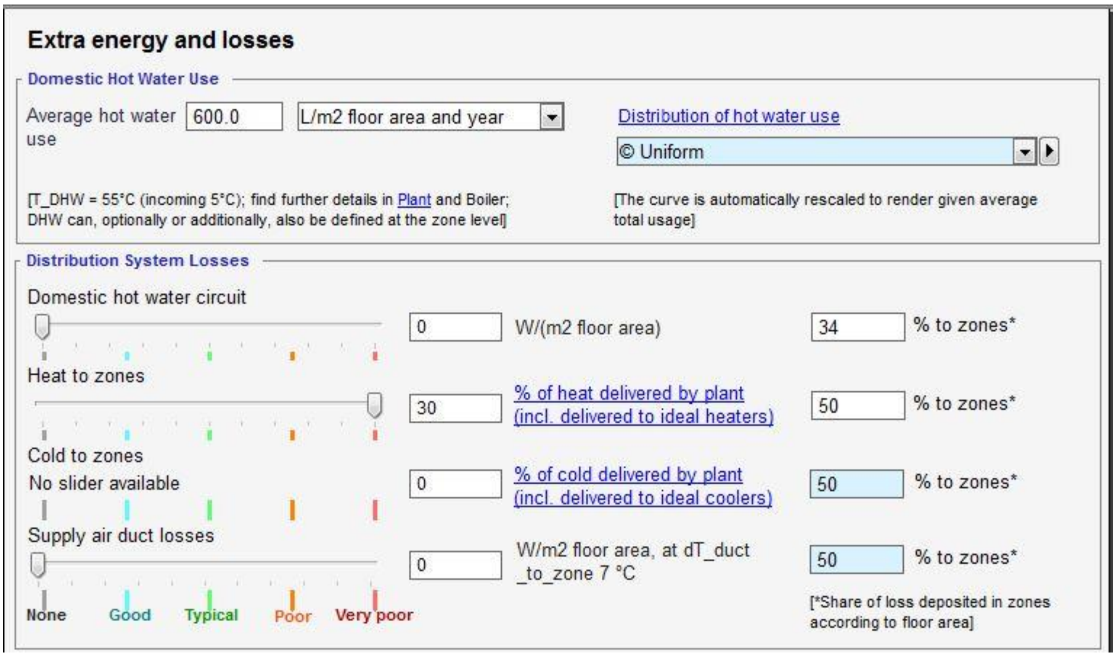

FIGURE 12. Extra energy losses

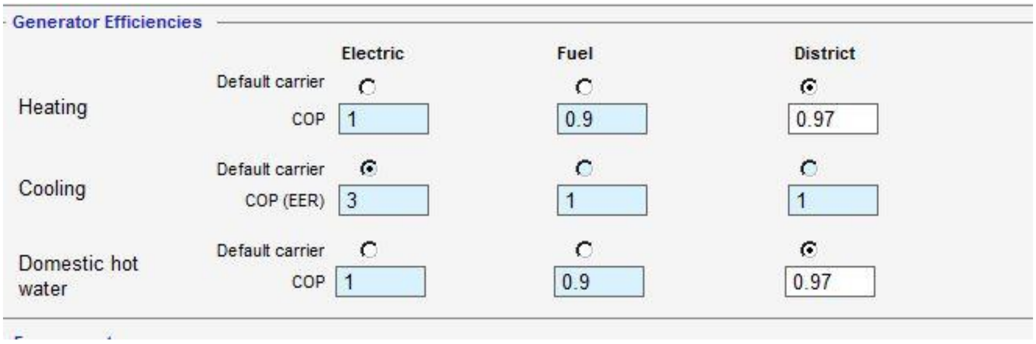

FIGURE 13. Coefficients of performance

To achieve effect of natural ventilation chimneys were put in every calculation zone. Inlet loss coefficient is equal to 1.0, outlet loss coefficient is equal to 0.6. Lengths of ducts are different because of floor height of zone.

For simulation of energy consumption will be created four principal models. The first of them will describe building energy needs before refurbishment. And the second model will be calculated with new parameters of glazing, third model will describe building with adding insulation and the last one will describe building after full refurbishment with insulation and glazing.

6.3 Simulation model 1

First simulation model will describe building energy needs before refurbishment. For simulation wooden windows of existing house are taken, which are in use in 606-series buildings. These windows are double glazed windows and opening into the room. Building has orientation 354 degree. Windows installed on two opposite sides of building envelope so that they are looked mostly forward on north and south. More numerical information is given in table 6.

TABLE 6. Windows properties

Windows	Area [m2]	U Glass [W/(K m2)]	U Frame [W/(K m2)]	U Total [W/(K m2)]	U*A [W/K]	Shading factor g
N	801.85	2.90	2.00	2.81	2253.20	0.76
S	822.15	2.90	2.00	2.81	2310.24	0.76
Sum	1624.001	2.902	2.002	2.812	4563.441	0.762

All constructions from table 7 are taken according with documentation from storage of technical decisions properties of typical multistorey residential buildings.

TABLE 7.Construction characteristics

Building envelope	Area [m2]	U [W/(K m2)]	U*A [W/K]	% of total
External walls	7027.99	0.71	4979.81	44.69
Roof	1751.91	0.33	583.04	5.23
External floor	1777.45	0.35	626.18	5.62
Windows	1624.00	2.81	4563.44	40.95
External doors	12.60	1.01	12.68	0.11
Thermal bridges			377.84	3.39
Sum1/Weighted average2	12193.941	0.912	11142.991	100.00

Extra heat losses could be caused by leakages through thermal bridges between parts of envelope. Values of C4 National Building Code, paragraph 2.4.9 and shown in table 8.

TABLE 8. Thermal bridges

Thermal bridges	Area or Length	Avg. Heat conductivity	Sum [W/K]
External wall - Internal slab	5629.30 m	0.015 W/(K m)	84.439
External wall - Internal wall	488.00 m	0.008 W/(K m)	3.904
External wall - External wall	370.30 m	0.060 W/(K m)	22.218
Window perimeter	4384.80 m	0.040 W/(K m)	175.392
External door perimeter	33.00 m	0.040 W/(K m)	1.320
Roof - External wall	326.50 m	0.080 W/(K m)	26.120
External slab - External wall	327.80 m	0.240 W/(K m)	78.672
Balcony floor-External walls	0.00 m	0.000 W/(K m)	0.000
External slab - Internal wall	0.00 m	0.008 W/(K m)	0.000
Roof - Internal wall	382.76 m	0.004 W/(K m)	1.646
Exteral walls - Inner corners	264.50 m	-0.060 W/(K m)	-15.870
Total envelope	12193.94 m2	0.000 W/(K m2)	0.000
Sum	-	-	377.841

Fixed infiltration airflow rate is 904.388l/s.

6.4 Simulation model 2. Refurbishment with replacing of windows

Second simulation model will describe building energy needs after refurbishment. In this case only windows will be replaced to new ones. For simulation of this building PVC windows will be chosen, model REHAU Sib-Design. They have improved properties than previous one. Properties of these windows are given in following table 9.

TABLE 9. REHAU windows properties

Windows	Area [m2]	U Glass [W/(K m2)]	U Frame [W/(K m2)]	U Total [W/(K m2)]	U*A [W/K]	Shading factor g
N	801.85	1.40	2.00	1.46	1170.70	0.61
S	822.15	1.40	2.00	1.46	1200.34	0.61
Sum	1624.001	1.402	2.002	1.462	2371.041	0.612

Other construction elements will be the same. No changes in heat gains, envelope insulation and shadings. All constructions are taken according with documentation from storage of technical decisions properties of typical multistorey residential buildings All values are shown in table 10.

TABLE 10. Input values for model 2

Building envelope	Area [m2]	U [W/(K m2)]	U*A [W/K]	% of total
External walls	7027.99	0.71	4979.81	56.03
Roof	1751.91	0.33	583.04	6.56
External floor	1777.45	0.32	563.37	6.34
Windows	1624.00	1.46	2371.04	26.68
External doors	12.60	1.01	12.68	0.14
Thermal bridges			377.84	4.25
Sum1/Weighted average2	12193.941	0.732	8887.781	100.00

Because of changes in windows amount of infiltration air flow rate will also change. And after refurbishment it becomes less up to 677.447l/s.

6.5 Simulation model 3. Refurbishment with adding of insulation

Third simulation model describe building after refurbishment using only added insulation. Constructions are taken according with documentation and insulation materials taken in the way to satisfy requirement thermal resistance of building envelope for St. Petersburg.

ROCKWOOL VENTI BATTS will use for additional insulation for walls. Properties of external wall with adding this insulation material is in the table 11.Thermal resistance is suitable for given conditions because it is bigger than requirement thermal resistance, which is equal 3.15 (K m2)/W.

TABLE 11. Construction of insulated external wall

Walls	ρ, kg/m^3	λ, W/m·K	δ, m	R, [(K m^2)/W]	U-value, [W/(K m^2)]
Concrete	1 500,00	0,38	0,40	1,05	0,950
ROCKWOOL VENTI BATTS	90,00	0,04	0,10	2,86	0,35
Plate	2 800,00	3,2000	0,035	0,01	91,429
				3,92	0,255

ROCKWOOL KAVITI BATTS will use for additional insulation for ceiling above basement. Refurbished construction of basement with technical characteristics is in table 12.Thermal resistance is suitable for given conditions because it is bigger than requirement thermal resistance, which is equal 4.15 (K m^2)/W.

TABLE 12. Construction of ceiling above basement

Basement	ρ, kg/m^3	λ, W/m·K	δ, m	R, [(K m^2)/W]	U-value, [W/(K m^2)]
Concrete	1 500,00	0,38	0,25	0,66	1,520
Concrete	1 000,00	0,23	0,30	1,30	0,767
ROCKWOOL KAVITI BATTS	50,00	0,04	0,10	2,56	0,390
Bitumen	1 200,00	0,2200	0,025	0,11	8,800
				4,64	0,216

Based on this improving of wall and ceiling construction general characteristics will be different from pre-refurbished situation. Walls with added insulation will give rather big effect on thermal resistance of building envelope and total heat losses also. Calculated by IDA ICE values of construction characteristics are given in table 13.

TABLE 13. Construction characteristics

Building envelope	Area [m2]	U [W/(K m^2)]	U*A [W/K]	% of total
External walls	7027.99	0.21	1492.97	20.26
Roof	1751.91	0.33	583.04	7.91
External floor	1777.45	0.19	338.30	4.59
Windows	1624.00	2.81	4563.44	61.93
External doors	12.60	1.01	12.68	0.17
Thermal bridges			377.84	5.13
Sum1/Weighted average2	12193.941	0.602	7368.261	100.00

Values of thermal bridges and leakage air the same as in first model.

6.6 Simulation model 4

Fourth simulation model describe building energy needs after full refurbishment. This model combined changes from model 2 and model 3. It has new PVC windows with good air tightness, and higher U-value than existing windows. It is also insulated according with calculations of requirement thermal resistance of building envelope for St. Petersburg region. In previous chapters all needed design technical characteristics were already mentioned. On the other hand overall construction characteristics, which are important input values, are given in table 14.Because of good tightness of windows amount fixed infiltration airflow rate is 667.447 l/s. It will cause additional reduce of energy consumption for whole building.

TABLE 14. Construction characteristics

Building envelope	Area [m2]	U [W/(K m2)]	U*A [W/K]	% of total
External walls	7027.99	0.21	1492.97	28.84
Roof	1751.91	0.33	583.04	11.26
External floor	1777.45	0.19	338.30	6.54
Windows	1624.00	1.46	2371.04	45.81
External doors	12.60	1.01	12.68	0.24
Thermal bridges			377.84	7.30
Sum1/Weighted average2	12193.941	0.422	5175.861	100.00

6.7 Result analyzes

During simulation in IDA ICE the major aim is to know energy consumption of building before refurbishment and after it. The most significant index of it is delivered energy. Delivery energy shows the amount of energy delivered to the building. This also could be named as net energy. In this paragraph will be shown as main factor annual energy consumption. For determination of refurbishment effectiveness and analyzing results will be chosen 3 pairs of simulation models. In every case pre-refurbished model will be taken as general for comparison and second model will be different for each case of comparison after refurbished building.

6.7.1 Comparison of existing building and building model 2

Firstly existing building will be compared with refurbished with new PVC windows. In the following table 15 can be seen the ratio of energy consumption in both cases. Looking on this table and comparing values of heating it is possible to notice, that amount of delivered energy decreased from 1116391 kWh to 839813 kWh, so it takes 24.77% from existing values. It says about high tightness of windows and their thermal protection properties.

TABLE 15. Total energy consumption

		Delivered energy, kWh	
		MODEL 1	MODEL 2
	Lighting, facility	138371	138371
	Electric cooling	0	0
	HVAC aux	33711	33711
	Total, Facility electric	172082	172082
	Fuel heating	1116391	839813
	Domestic hot water	580608	580608
	Total, Facility fuel*	1696999	1420421
	Total	1869081	1592503
	Equipment, tenant	301962	301962
	Total, Tenant electric	301962	301962
	Grand total	2171043	1894465

6.7.2 Comparison of existing building and building model 3

Secondly existing building with refurbished insulation of external walls and basement ceiling will be compared. Results are shown in table16.Basing on the obtained values it is possible to notice that energy consumption was also reduced. This time from 1116391 kWh to 672333 kWh, so it takes 39.78% from existing values. This value is bigger than in previous comparison. One of the reasons could be enough poor existing building shell. It is made only from cinder blocks, with high heat transfer coefficient. It leads to significant heat losses and possibility of condensation. And after addition of modern insulation material this problems could disappear and keep heat inside of building. Anyway it says about good thermal insulation properties.

TABLE 16. Total energy consumption

		Delivered energy, kWh	
		MODEL 1	MODEL 3
	Lighting, facility	138371	138371
	Electric cooling	0	0
	HVAC aux	33711	33711
	Total, Facility electric	172082	172082
	Fuel heating	1116391	672333
	Domestic hot water	580608	580608
	Total, Facility fuel*	1696999	1252941
	Total	1869081	1425023
	Equipment, tenant	301962	301962
	Total, Tenant electric	301962	301962
	Grand total	2171043	1726985

6.7.3 Comparison of existing building and building model 4

Last comparison is about existing building and full refurbished including replacement of window and additional thermal insulation. It is predictable, that difference in energy consumption will rather big. It is because of good tightness of windows and theirs lower U-value compared with previous type of window frames. Effect on reducing of energy consumption also will have improved thermal conductivity of exterior wall, which will cause less heat losses through building envelope. So for clarity, the results of monthly energy consumption can be seen in table 17. It is easy to see that amount of delivered energy decreased from 1116391 kWh to 430778 kWh. In this case difference takes 64.41%.

TABLE 17. Monthly energy consumption for heating

Month	MODEL 1		MODEL 4	
	(kWh)	Prim., (kWh)	(kWh)	Prim., (kWh)
January	219423	153596.1	93329	65330.3
February	189169	132418.3	78947	55262.9
March	162777	113943.9	62158	43510.6
April	71641	50148.7	24169	16918.3
May	11365	7955.5	3173	2221.1
June	4811	3367.7	3071	2149.7
July	3173	2221.1	3173	2221.1
August	3187	2230.9	3173	2221.1
September	17354	12147.8	3071	2149.7
October	79726	55808.2	18597	13017.9
November	154475	108132.5	56207	39344.9
December	199290	139503.0	81710	57197.0
Total	1116391	781473.7	430778	301544.6

Amount of delivered energy decreased from 1116391 kWh to 430778 kWh. In this case difference takes 64.41%.

On the fugure14 ratio between energy consumption of model 1 and model 4 is shown on diagram.

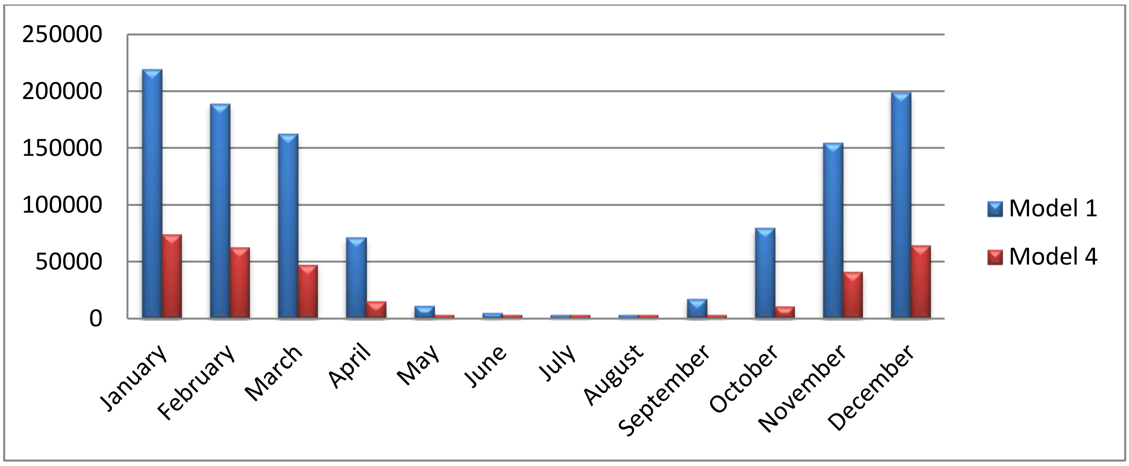

FIGURE 14.Monthly Delivered Energy for pre-refurbished and refurbished building

Summarizing results, effect of refurbishment are noticeable in every case, but the last case is the most efficient. More insulation layers provide low meaning of U-value and because of that less heating energy will transfer to surroundings. Risk of condensation will eliminate totally. Insulation will prevent the appearance of water drops on materials. Comparison of all types of refurbishment is clearly shown on diagram on figure 15.

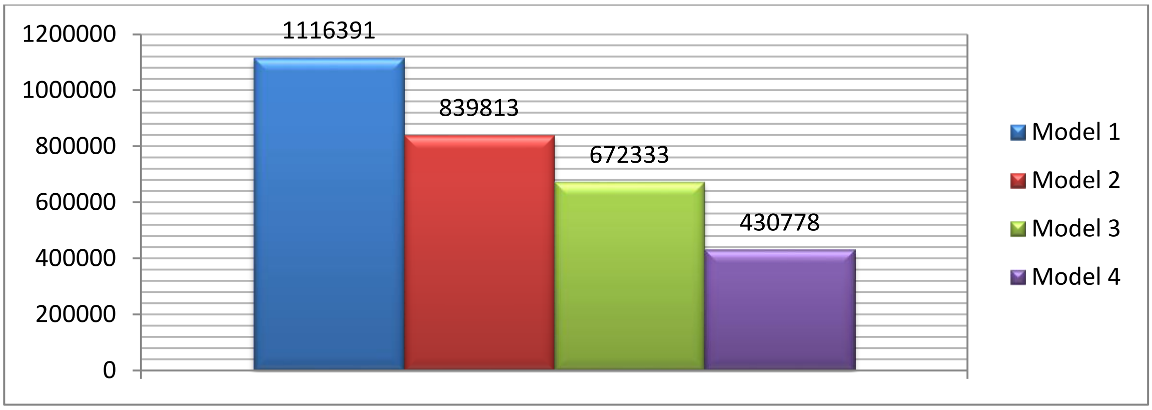

FIGURE 15.Delivered Energy for all models

Next not less reasonable element of refurbishment is windows. They are providing satisfactory index of thermal resistance. These properties will lead to reducing energy consumption. And amount of leakage air will decrease. From one point of view it is not good, because amount of fresh air will decrease and natural air change rate will be considerably less. But on the other hand cold air from street won’t come into apartments so it will cause fewer reasons for draught.

7 CALCULATION OF PAYBACK

Calculations of capital costs, investment efficiency and some other on this chapter are made with Microsoft Excel program.

7.1 Materials for refurbishment

Firstly consider the cost of insulation. As it said earlier for insulation was chosen ROCKWOOL insulation. In table 18 prices are given in rubles. It is because of the building situation in Russia St. Petersburg. Prices for needed materials are asked up to

15th of November 2013. Prices have been taken as average price level for selected product.

For calculation total capital cost it is necessary to summarize all contents of refurbish process. They are price for materials, instruments and installation works

TABLE 18. Prices for insulation installation

	Amount of material, m2	Cost per unit, rub/m2	Capital costs, rub
ROCKWOOL VENTI BATTS	7 499,23	300.00	2 249 769,65
ROCKWOOL KAVITI BATTS	1 920,81	197.80	379 936,81
CHESCO Hydro and vapor insulation	7 499,23	14.63	109 750,00
Plate	7 499,23	14.52	108 883,05
Installation	9 420,05	1350.00	12 717 061,00
		TOTAL	15 565 400,51

Looking on this calculations total price for installation of insulation is 15 565 400,51. But in practical if contractor receives a facility of this magnitude they will give a discount for works. Approximately discount equal 35% from total price. In this way price for wall and basement refurbishment will be:

15 565 400,51-35%=10117510,33 rub

EUR exchange rate for November 2013 is 229 943,42 euro.

Next consider the cost of windows. For insulation was chosen REHAU Sib-Design. System. Prices for repairing windows were given by manufacture. These prices already include cost for unit of equipment and installation. Calculation is shown into the table 19.

TABLE 19. Prices for windows installation

	units	rub/unit	rub
REHAU Sib-Design. System With installation	800	12 365,00	9 892 000
		TOTAL	9 892 000

Based on this calculations total price for installation of windows is 9 892 000.00. As in previous variant contractor could give a discount for works. Approximately discount equal 40% from total price. In this way price for windows installation will be:

9 892 000-40%=5 935 200 rub

EUR exchange rate for November 2013 is 134 890euro.

Total investments in refurbishment is:

10117510,33+5 935 200=16 052 710 rub= 364834 euro.

7.2 Prices for district heating

Every year prices for energy grows and that is why energy saving of buildings is rather important. All prices for district heating are taken from web-site of municipal board of St. Petersburg for customers. Grows of prices shown on diagram on figure 16./17./

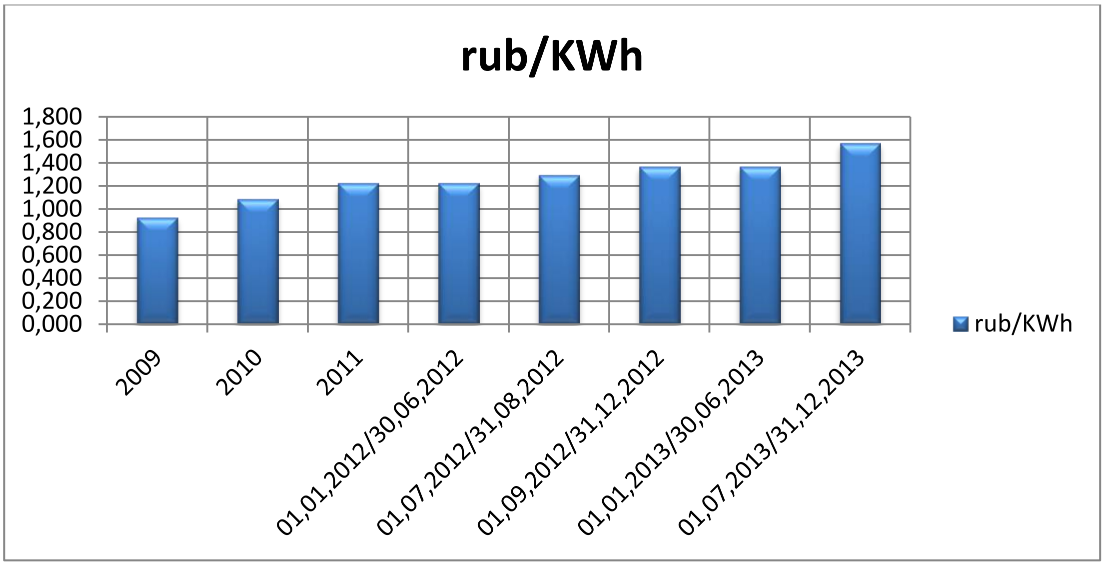

FIGURE 16. Existing prices for heating power in St. Petersburg

On this diagram it is seen that prices every year goes upper. Because of calculation for payback is a needed cost for kWh in next several years. By finding the dependence of growing prices for heating power will be the next, as shown on figure 17.Obtained dependence is close to 10% of grows from previous year to the next.

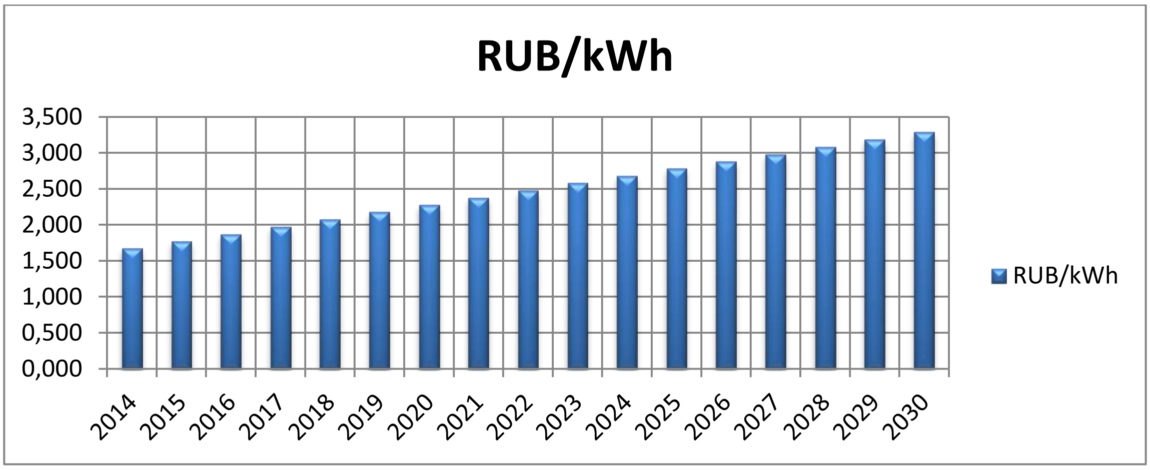

FIGURE 17.Predictableprices for heating power in St. Petersburg

7.3 Calculation of payback

Payback period is the time in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment. It is one of the simplest investment appraisals techniques. Payback Period depends on capital cost of refurbishment and operating cash flows are equal for each time period of expected period. For purposes of clarity further calculations will be presented in euros.

Firstly will be calculated annual price for hearing energy based on predictable prices and calculated energy consumption with IDA ICE. By this way it will show into the appendix 1, table 1 which difference will be between three methods of renovation. And prices could chance according with different annual energy consumption./20./

For the calculation of the annual cash flows by years will be applied formula 4. In previous chapter it was mention that prices getting higher with certain ratio, which will be added in formula.

$$R_i = Q \cdot a_0 \cdot \alpha \quad (4)$$

Where

R_i	Cash flow by years, euro
a_0	Annual fee for kWh, euro/kWh
α	Factor, depending grows of fee
Q	Amount of delivered heating energy, kWh

Looking on this table it is possible to mention, that in first years annual fee for heating is given for all models in one raw. It is because time of refurbishment, which will be made in 2013. That is why fee is taken for building energy consumption before the refurbishment. In the next raw it is easily seen how annual fee for refurbished buildings heating needs decreases from year to year.

To evaluate investment efficiency will be used: the net present value (NPV), profitability index (PI) and payback period (Tpb). When NPV getting positive value it means the beginning of payback period. Payback will determine in years.

NPV will be calculated by formula 5.

$$NPV = \Sigma(I + (R' - R)) \quad (5)$$

NPV	Net present value, euro
I	Investments, euro
R’	Cash flow per years before refurbishment, euro
R	Cash flow per years after refurbishment, euro

Profitability index (PI) shows the ratio between the sum of cash flow from operating activities to the absolute value of cash flow from investing activities to the project. Profitability index helps to understand investment efficiency. If PI<1 project does not start to make incomes yet. But if value of PI>1, it means that project give benefits to investors. Formula 6 describe method of profitability index’s calculation.

$$PI = \frac{NPV}{I} \quad (6)$$

PI	Profitability index
NPV	Net present value, euro
I	Investments, euro
R	Cash flow by years, euro

Results of calculations were made in table form in Excel program. Calculations for all variants of refurbishment are shown in Appendix 1. For Case with replacing of windows calculations are shown in Appendix1 table 2, for case with additional insulation are given in Appendix1 table 3and for full refurbishment calculations are shown in table 4.

Results of relative payback period by comparison of existing building and building model 2 with replaced windows are shown on figure 18.Based on the result of calculations payback period for the refurbishment with windows replacing will be Tpb=11 years, NPV= 150549 euro, PI= 1,116>1.

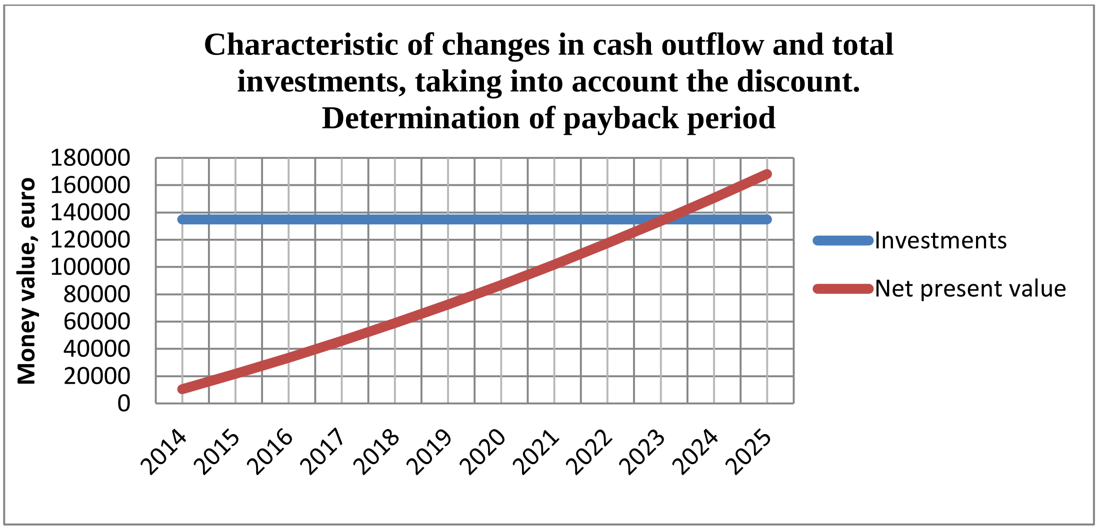

FIGURE 18. Payback period time after refurbishment with windows replacing

Results of relative payback period by comparison of existing building and building model 3 with additional insulation are shown on figure 19. Based on the result of calculations payback period for the refurbishment with windows replacing will be Tpb= 7 years, NPV= 139553euro, PI= 1,035>1.

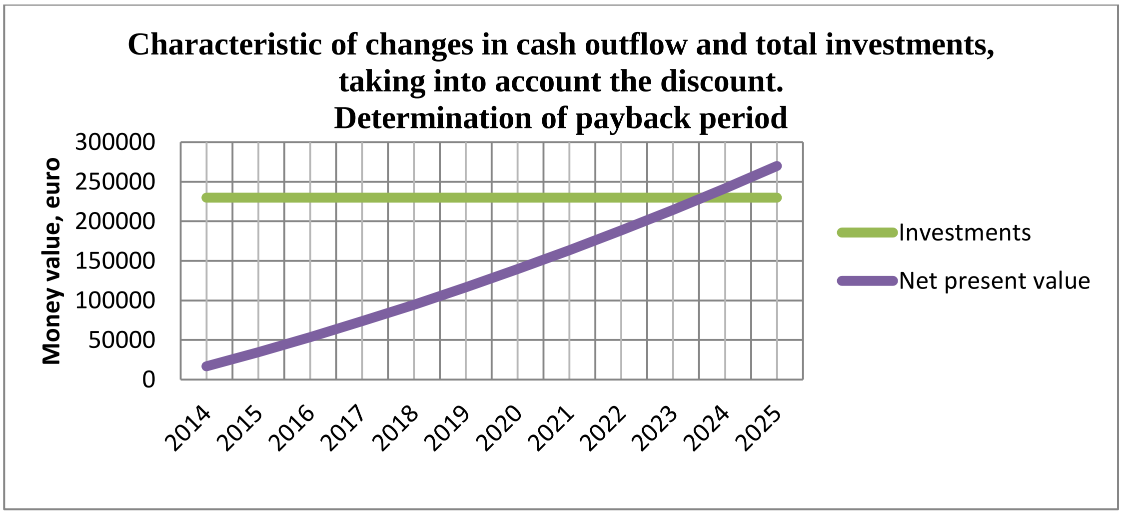

FIGURE 19. Payback period time after refurbishment with additional insulation

Results of relative payback period by comparison of existing building and building model 4 with replacing windows and additional insulation are shown on figure 20. Based on the result of calculations payback period for the refurbishment with windows replacing will be as in comparison with model 2 Tpb= 11 years, NPV= 373198 euro, PI= 1023>1.

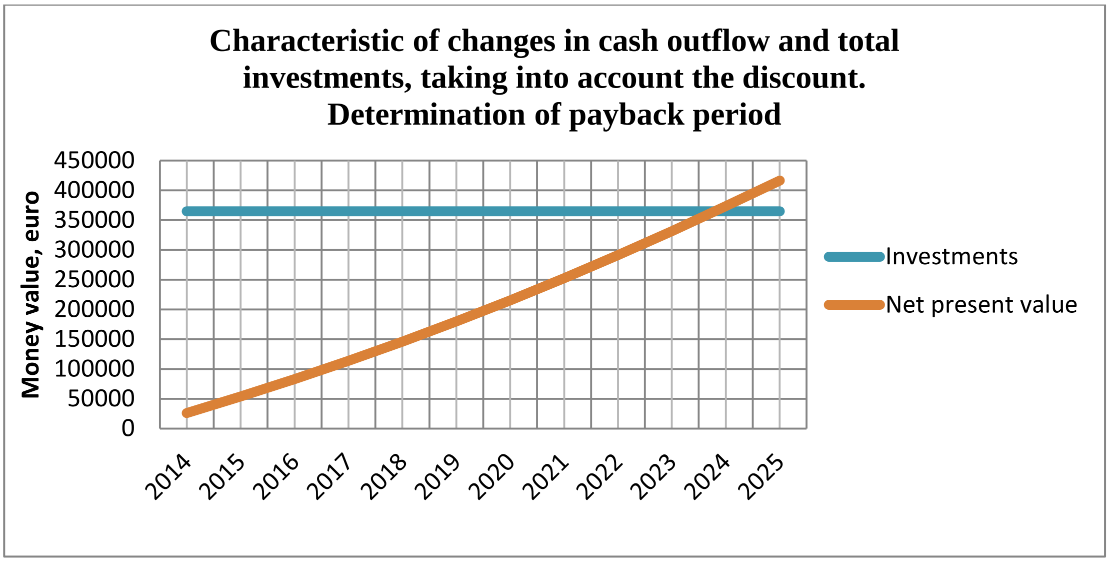

FIGURE 20. Payback period time after full refurbishment

8 ANALYSIS OF THE RESULTS

The results of simulation process will give defined answer for the first question of this research. Due to IDA ICE program the most efficient way of refurbishment was founded. The main criteria to determine the most efficient method was comparison of delivery energy needs between existing building and building after refurbishment. After refurbishment with use of replacement windows to more modern ones and with additional insulation to the external walls and basement ceiling energy consumption decreases up to 64.41% from existing.

Secondly calculation shows the most financially profitable project with the shortest payback. On the other hand another project has the similar payback period and it is more energy efficient. For more clarity analysis are presented into table 20.

TABLE 20.The summary table

	Model 1	Model 2	Model 3	Model 4
Q, kWh	1 116 391	839 813	672 333	430 778
Inflow in the first year	-	16 859	22 993	41 792
Profitability index	-	1,116	1,035	1,023
Payback period, years	-	11	7	11

Figure 21 gives visual presentation of payback period for different variants of refurbishment basis on this research. It may be recalled that model 2 describes building energy needs after refurbishment only with windows replacing. Model 3 describes building energy consumption after refurbishment with additional insulation layer. Model 3 combined two previous ways of improving building envelope.

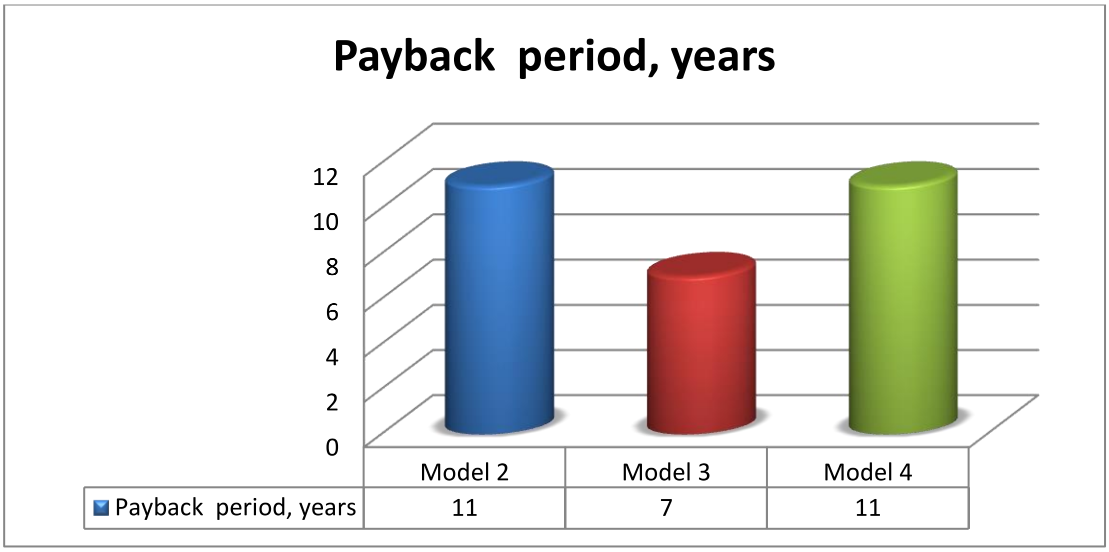

FIGURE 21. Payback period time after full refurbishment

Analyzing figure 21 it could be possible that both model 2 and model 4 are acceptable for implementation in real life. But if take into account money inflows till the first payback year, it will be seen that model 4 is much more economical efficient than model 2. The following dependence shown on pie chart in figure 22.

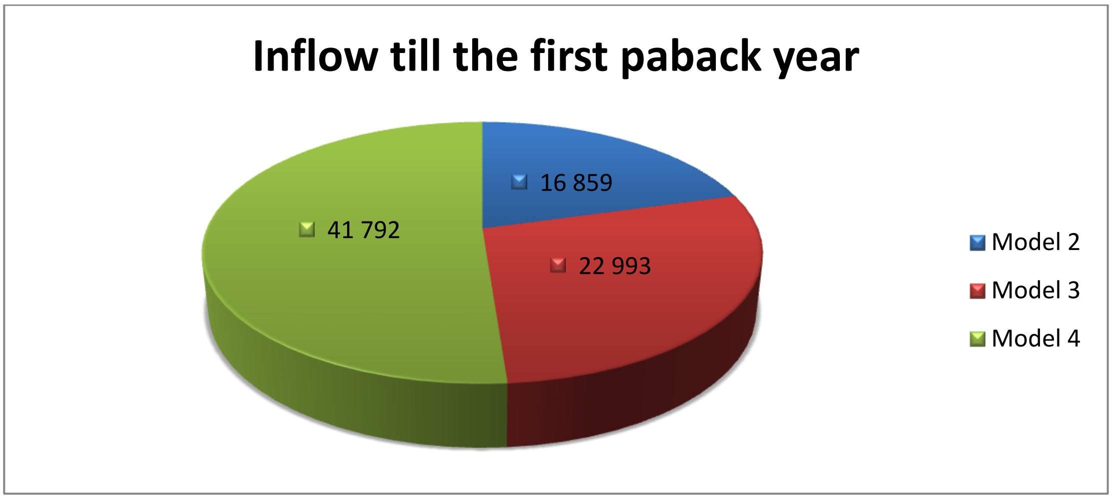

FIGURE 22.Inflow till the first payback year

9 CONCLUSION

Reducing of heat losses of building has significant role for residents as for theirs quality of life. Refurbishment will reasonably improve quality of building envelope and indoor quality. Due to such renovation it is possible to achieve reducing of heat losses. While windows will be replaced to more tightness, and insulation layer will satisfy requirements, energy consumption could be reduces up to 61.4%. It means that heat will be keep inside the building and provide good conditions.

Also capital costs were founded during this research. The most expensive case takes about 364 834 euro with current prices for materials and works. This price seems to be enough high, but if we divide it on amount of apartments into the building it comes 2027 euro/apt. So it means that in general everyone could pay this fee to improve own quality of living.

The final aim is to find out payback period of renovation was also achieved. Payback period was founded from the difference of initial investments in refurbishment and the annual fee for heating of refurbished building to monetary costs for pre-refurbished building heating needs. For this case payback period will be 11 years. This period is rather long, but anyway users will feel benefit from the investment in this refurbishment during all time of presence into the refurbished building. And after this 11 years users will feel noticeable effect for theirs budget.

By this way if governments or residents would decide to refurbish multistorey 606-series building, it would be better to make general renovation, including both windows and insulation. Even it took more capital investments it will give enough rapid payback, more benefits and good indoor climate quality after refurbishment.

Today with high developing industry of construction properties of modern materials will be better from year to year. It will cause more possibilities to improve building envelope. Generally this buildings has satisfy quality for residents. Based on this next changes for envelope could give better results if more efficient types of materials will be applied.

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APPENDIX1(1).

Appendix on several pages

TABLE 1. Annual fee for heating

		Annual fee, euro			
		Model 1	Model 2	Model 3	Model 4
		1 116 391	839 813	672 333	430 778
	Euro/kWh	kWh	kWh	kWh	kWh
2009	0,021	23 482			
2010	0,025	27 474			
01,2011/12,2011	0,028	30 985			
01,2012/06,2013	0,028	30 985			
07,2012/08,2012	0,029	32 844			
09,2012/12,2012	0,031	34 674			
01,2013/06,2013	0,031	34 674			
01,2013/12,2013	0,036	39 875			
2014	0,038	42 437	31 923	25 557	16 375
2015	0,040	44 998	33 850	27 100	17 363
2016	0,043	47 559	35 777	28 642	18 352
2017	0,045	50 121	37 704	30 185	19 340
2018	0,047	52 682	39 631	31 727	20 328
2019	0,049	55 244	41 558	33 270	21 317
2020	0,052	57 805	43 484	34 813	22 305
2021	0,054	60 367	45 411	36 355	23 293
2022	0,056	62 928	47 338	37 898	24 282
2023	0,059	65 490	49 265	39 440	25 270
2024	0,061	68 051	51 192	40 983	26 259
2025	0,063	70 613	53 119	42 526	27 247
2026	0,066	73 174	55 046	44 068	28 235
2027	0,068	75 735	56 973	45 611	29 224
2028	0,070	78 297	58 899	47 153	30 212
2029	0,072	80 858	60 826	48 696	31 201
2030	0,075	83 420	62 753	50 239	32 189

APPENDIX1(2).

Appendix on several pages

Table 2. Calculation of the payback period and net present value NPV for model 2

	Investments, euro	Cash flow per years before refurbishment, euro	Cash flow per years after refurbishment, euro	Net present value	Profitability index
Year	I	R'	R	NPV	PI
2014	134891	42 437	31 923	10 513	0,078
2015		44 998	33 850	21 661	0,161
2016		47 559	35 777	33 444	0,248
2017		50 121	37 704	45 861	0,340
2018		52 682	39 631	58 913	0,437
2019		55 244	41 558	72 599	0,538
2020		57 805	43 484	86 920	0,644
2021		60 367	45 411	101 875	0,755
2022		62 928	47 338	117 465	0,871
2023		65 490	49 265	133 690	0,991
2024		**68 051**	**51 192**	**150 549**	**1,116**
2025		70 613	53 119	168 043	1,246
2026		73 174	55 046	186 171	1,380
2027		75 735	56 973	204 934	1,519
2028		78 297	58 899	224 331	1,663
2029		80 858	60 826	244 363	1,812
2030		83 420	62 753	265 030	1,965

APPENDIX1(3).

Appendix on several pages

Table 3. Calculation of the payback period and net present value NPV for model 3

	Investments, euro	Cash flow per years before refurbishment, euro	Cash flow per years after refurbishment, euro	Net present value	Profitability index
Year	I	R'	R	NPV	PI
2014	229943	42 437	25 557	16 880	0,125
2015	229943	44 998	27 100	34 778	0,258
2016	229943	47 559	28 642	53 696	0,398
2017	229943	50 121	30 185	73 632	0,546
2018	229943	52 682	31 727	94 587	0,701
2019	229943	55 244	33 270	116 561	0,864
2020	**229943**	**57 805**	**34 813**	**139 553**	**1,035**
2021	229943	60 367	36 355	163 565	1,213
2022	229943	62 928	37 898	188 595	1,398
2023	229943	65 490	39 440	214 645	1,591
2024	229943	68 051	40 983	241 713	1,792
2025	229943	70 613	42 526	269 800	2,000
2026	229943	73 174	44 068	298 906	2,216
2027	229943	75 735	45 611	329 030	2,439
2028	229943	78 297	47 153	360 174	2,670
2029	229943	80 858	48 696	392 336	2,909
2030	229943	83 420	50 239	425 517	3,155

APPENDIX1(4).

Appendix on several pages

Table 4. Calculation of the payback period and net present value NPV for model 4

	Investments, euro	Cash flow per years before refurbishment, euro	Cash flow per years after refurbishment, euro	Net present value	Profitability index
Year	I	R'	R	NPV	PI
2014	364834	42 437	16 375	26 062	0,071
2015	364834	44 998	17 363	53 696	0,147
2016	364834	47 559	18 352	82 904	0,227
2017	364834	50 121	19 340	113 685	0,312
2018	364834	52 682	20 328	146 039	0,400
2019	364834	55 244	21 317	179 966	0,493
2020	364834	57 805	22 305	215 466	0,591
2021	364834	60 367	23 293	252 540	0,692
2022	364834	62 928	24 282	291 186	0,798
2023	364834	65 490	25 270	331 405	0,908
2024	**364834**	**68 051**	**26 259**	**373 198**	**1,023**
2025	364834	70 613	27 247	416 563	1,142
2026	364834	73 174	28 235	461 502	1,265
2027	364834	75 735	29 224	508 014	1,392
2028	364834	78 297	30 212	556 098	1,524
2029	364834	80 858	31 201	605 756	1,660
2030	364834	83 420	32 189	656 987	1,801